Drainage of Peat and Muck Lands

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Peat and muck soils have unique biological, physical, and chemical properties, and on them the common drainage and management practices that are used on mineral soils are not suitable.

Biologically the organic soils support hosts of micro-organisms, mostly bacteria, which are largely responsible for the formation and alteration of the peat. The action of the anaerobic micro-organisms builds up the organic soils. The aerobic organisms are largely responsible for decomposition.

The soils have a dark color, light weight, and an absorptive, spongelike texture. They have high absorptive and radiant properties, a high heat capacity, and low heat conductivity. They burn at relatively low temperatures and have a high cation exchange and a high buffer capacity, which strongly resists changes in acid reaction. Peats tend to be acid, but range from pH 3.5 to 8.0.

The peat and muck soils cover an estimated 80 million acres in the United States, mostly in the cool, temperate, humid region of Maine, Massachusetts, New York, and New Jersey, and the Great Lakes States of Michigan, Wisconsin, Minnesota, Illinois, and Indiana. Minnesota, Wisconsin, and Michigan have about 75 percent of the total peat and muck lands in this country.

Large bog deposits exist in the warm-temperate, humid region within the southeastern coastal plain swamps of Virginia, North Carolina, and Georgia, and along the coastal marsh tidelands of Louisiana and Texas. The subtropical, humid region of Florida, including the Everglades and related localities, make up 14 percent of the total national deposits. Other deposits, in the Pacific coastal area, include the California delta peats, formed where the climate is hot and dry, and the semiarid to subhumid marsh and valley deposits in Washington and Oregon.

The Everglades, more than 2 million acres, is the largest known tract of peat and muck soils in the world. Other large tracts occur in the delta area of California, along the coastal marshes of Louisiana and Texas, and in Michigan, Minnesota, and Wisconsin. The bulk of peat and muck lands, however, are in small pockets of 1 acre to several hundred acres scattered over thousands of farms. The deposits are valuable for crop production, water reservoirs, and wildlife refuges, and as a source of organic materials.

Peat and muck soils, however, vary widely and some of them hold little in the way of ordinary agricultural possibilities. Efforts to reclaim them often have failed because the soil was poor, they were far from markets, and they were subject to frosts. On the other hand, proper management of the good, well-situated lands has been successful, and the better soils near city markets may be valued at a thousand dollars or more an acre.

Besides crop production, 256,000 tons of peat were used in the United States in 1950—63 percent for soil improvement, 22 percent in mixed fertilizers, 12 percent for poultry litter and stable bedding, and 3 percent for miscellaneous purposes. The organic soils are also potentially a source for fuel, producer gas, and for basic organic chemicals produced by distillation and carbonization. The total value of peat and muck lands in the United States has been appraised at approximately 40 billion dollars.

PEAT AND MUCK have been created from the vegetation of bogs, marshes, and swamp forests, or from sphagnum mosses, by the action of micro-organisms, largely bacteria.

Soil technicians define peat as a soil that has less than 50 percent of mineral matter, on a dry weight basis; muck as a soil having 50 to 80 percent of mineral matter; and mineral soils as those having more than 80 percent of ash after burning. Peat soils are only partly decomposed and retain a fibrous or granular texture. The mucks are thoroughly decomposed and are finely textured, uniform, amorphous, and black.

The principal types of peat are sedimentary, fibrous, woody, and sphagnum. The first three are formed in basins or on poorly drained lands. The sphagnum moss type may develop on higher land.

Sedimentary peats are derived primarily from submerged, succulent, open-water plants, such as naiads and pondweeds, which contain relatively small proportions of cellulose or hemicellulose materials. These may be mixed with algae, and dead microorganisms, with fallen pollen and leaves from the higher plants, together with wind or waterborne mineral sediments.

Fibrous peats are composed of the remnants of reeds, sedges, and related marsh plants, which grow in shallow water along the edge of marshes. The fibrous peats contain a reasonably high proportion of cellulose. The water-holding capacity of the fibrous peats is high, and the water transmissibility is satisfactory. They are less acid than the moss peats and have a more desirable texture for tillage than the sedimentary peats. They contain from 2.0 to 3.5 percent of nitrogen. Many of the fibrous peats are suitable for agricultural purposes.

Woody peats are formed from the climax vegetation in swamp deposits. They develop from the residue of trees and shrubs which occupy the forest floor of the swamp. Ordinarily less calcium and other minerals reach the woody peats. Thus they are normally more acid than the fibrous type. Woody peat has a lower water-holding capacity than fibrous peat, and when drained provides a loose, granular and blocky structure, through which water moves readily. This soil has excellent tilth and usually is rated intermediate between fibrous and sedimentary peats as a field soil.

Studies of ancient climate indicate that the last continental glacier reached its greatest advance about 11,000 years ago and slowly retreated for 5,000 or 6,000 years to its present position. Thus, we may assume that the peat deposits which were laid down in depressions resulting from the last glacial retreat are younger than 10,000 years. The age of some of the northern deposits ranges from about 2,500 to 8,000 years. The Everglades peats of Florida appear to have developed over the past 5,000 years.

In Maine, Washington, the Great Lakes States, and Canada, moss peat is formed. Cool, damp weather favors the development of the deposits. Extensive areas also occur in northern Europe. This peat is formed principally from sphagnum mosses and associated vegetation, which depend on rainfall, dews, and fogs for moisture.

The sphagnum peats can hold up to 15 or 16 times their weight of water and absorb moisture to the extent that they actually lift the water table above the surrounding country. They build up by layers and sometimes reach a thickness of 30 feet. Customarily they present a dome-shaped surface profile. Soils formed under these conditions are commonly termed high-moor peats. They are extremely acid—pH 3.5 to 4. They are not readily decomposed.

This type of peat is a poor medium for the growth of organisms causing decomposition, and the nitrogen content is low. Even when drained it is a poor soil for the growth of the higher plants, unless the acidity is corrected by the heavy use of lime, and a complete fertilizer, including nitrogen and the microelements, is added. Even then, several years may be required to build up a population of soil organisms suitable for growing crops. Its principal uses are for the improvement of other soils, for packing plants and flowers, as an absorbent litter for stables and poultry houses, and for related uses where its high water-holding capacity is of value.

A UNIQUE FEATURE of organic soils must be considered before their reclamation is begun. Peat and muck lands are subject to subsidence—they lose surface elevation — when they are drained. The subsidence is caused by shrinkage due to drying, loss of the buoyant force of ground water, compaction, slow oxidation, burning, and wind erosion.

The average subsidence rate in the Everglades has been about 1.25 inches a year, and 50 years of drainage has resulted in the loss of some 40 percent by volume of the better agricultural soils. The organic soils in the Sacramento-San Joaquin delta area in California are reported subsiding at the rate of approximately 3 inches a year.

In virgin organic soils, loss in elevation is most rapid immediately following drainage and cultivation. The loss varies with the firmness of the peat and its structure. Sedimentary peats may lose as much as three-fourths of their drained volume very rapidly. Fibrous and woody peats ordinarily lose much less. Before cultivation, most fibrous peats have practically the same density from top to bottom, but in 5 years or more of tillage the top 18 inches increase in density to about double that of the peat underneath. The cultivated layer changes into an amorphous mass, the color darkens, the seepage rate declines, and the peat is transformed into a mucky condition. The increase in density brings a corresponding loss in volume.

As drainage continues, the rate of subsidence levels off to a slow, steady rate. The loss continues as long as the land is drained, and is due to slow oxidation caused by the action of aerobic micro-organisms in converting organic matter into carbon dioxide and other gaseous products. The rate at which the soil is consumed depends primarily on the depth of water table for a given soil type.

S. A. Waksman and his coworkers at Rutgers University found that the action of destructive bacteria was highest in the drained, low-moor peats and lowest in the extremely acid, high-moor peats. When the acid peats were treated with lime, manured, and put under cultivation, however, the micropopulation increased to about the same as that in the low-moor peats under similar drainage. Working with samples of low-moor peats, the investigators determined that the moisture content controlled the speed of decomposition. A moisture content of 50 to 80 percent of the total moist weight of the peat gave maximum rates of decomposition. Above and below that range the rate rapidly diminished. Some 20 percent of the dry weight of the original peat sample was decomposed at a moisture content of about 70 percent in 19 months; most of it was lost into the air as carbon dioxide. The organisms were active only when soil temperatures remained above 40° F.

Peat and muck water-table plots were established at the Everglades Experiment Station of the University of Florida near Belle Glade and at the Muck Crop Experiment Station of Purdue University at Walkerton, Ind.

It was discovered that the subsidence depended mainly on depth of the water table but that the rate in Indiana was a little less than one-half that in Florida. For average water-table depths of 12 inches, 24 inches, and 36 inches, the corresponding annual subsidence rate was approximately 0.6 inch, 1.4 inches, and 2.3 inches in the Everglades; and 0.1 inch, 0.6 inch, and 1.1 inches in Indiana. The plots were on soils that had already taken their initial shrinkage. In the Florida experiment, the prescribed water table was held all year; in the Indiana experiment, it was held only during the crop year from May to September.

Reference plates set below the permanent water table at the Everglades station showed that all soil shrinkage occurred above the water table. Studies of volume and ash indicated that the lowering of the surface on those plots could be attributed only slightly to compaction and was caused largely by oxidation.

On drained lands not cultivated or grazed, the drained zone develops an open, spongy texture, which allows free aeration. When such soils are plowed later, the loss of soil mass has been greater than the loss from adjacent tilled lands under the same water levels. It is assumed the compactness caused by cultivation inhibits aeration and retards oxidation. Hence, drained lands of this class should be put into use immediately.

Organic soils will burn when dry. Careless and uncontrolled burning destroys large areas each year. A peat fire is hard to put out and will burn until the soil is saturated by rainfall or by flooding. Burning reduces the soil depth and may leave the ground in an uneven, pitted condition that is unsuitable for farming.

Blowing, which removes soil and injures tender plants, is a problem in clean-tilled organic soils, especially right after cultivation when the surface is dry and powdery. Wind losses can be reduced by maintaining proper soil moisture and using a heavy corrugated roller, which leaves a ridged surface. Windbreaks are used in some muck areas to deflect the air currents and reduce soil movement.

THE MOST PRACTICAL way now known of reducing the loss of peat and muck soils is by controlled drainage that holds the water level as high as crop and field requirements permit before drainage.

The first step is to determine if the quality of the soil is suited for the intended crops. The acid peats are less valuable for most farm crops than the high-lime soils. Such special crops as cranberries can be grown on the acid peats. Some soils can be made productive by adding lime, but the peat colloid complex is naturally acid and much more lime is needed to raise the pH of a peat, as compared to a mineral soil. Many crop failures have resulted from attempts to develop the acid peats for crops to which they were unsuited. A simple test of acidity would have forestalled such ill-advised ventures.

Fibrous and woody peats generally are better for agricultural use than the sedimentary and moss peats. Mucks contain mineral admixtures, which are more likely to supply potash, phosphate, and the microelements necessary for plant growth. They tend to be more fertile than the peats.

The effectiveness and cost of measures to control surface and soil water may be largely determined by the depth and type of the peat or muck and the kind of underlying rock or subsoil. If the underlying material is hard rock or otherwise untillable, the depth of the organic soil should be at least 3 to 5 feet to justify drainage because of eventual subsidence.

Soft organic soils, such as the sedimentary peats, will have a greater incipient shrinkage loss than the firmer fibrous or woody peats. In virgin peats intended for cultivated crops, a minimum depth of 5 feet is desirable. Firm peats that have taken their initial shrinkage and land intended for use as permanent pasture should be at least 3 feet deep to warrant development.

If the peat or muck overlays fertile, tillable soil, the situation is quite different; then even shallow bogs may be recommended for cultivation. Minimum depths of organic soil may be ordinary plow depths if the subsoil, such as a shelly sand, is rich in lime, which is considered desirable.

If a permeable substratum near the ground surface is capable of carrying a large flow of water, dikes and ditches are ineffective in cutting off inflow from outside lands, and it will be difficult to hold different water levels in the same or adjoining fields. In moderate to shallow soils, where the field ditches cut into the permeable stratum and peripheral water levels are not too high, however, subdrainage will be good, and spacing of the field drains can be increased for drainage and subirrigation.

If the permeable beds act as artesian aquifers to bring outside water under pressure into the developed tract, special drainage methods involving relief wells may be required.

If the subsoil is a nonpermeable material, such as a plastic silt or clay, there will be relatively little seepage, but closer spacing of field drains will be required.

On drainage projects where roads must be built and foundations secured for water-control structures, their cost will depend largely on the suitability of the substrata.

Besides the inherent chemical and physical nature of the soil and the character and depth of the substratum, the value of the organic deposit is influenced by the location, topography, and water supply. It should be located close to existing roads and markets so that transportation costs will not be exorbitant. It should be situated so that outfall drainage, either by pump or gravity, is feasible at reasonable cost. The tract should be level enough so that a system of water-level controls may be installed economically. A source of irrigation water for maintaining proper soil moisture is highly desirable.

All those factors should be considered in the preliminary investigation to ascertain whether a favorable cost-benefit ratio appears to be forthcoming before making detailed plans for drainage. The same principles hold for the evaluation of cost-benefit ratios for the drainage of organic soils as for mineral soils. It should be kept in mind, however, that the organic soils have limited life, productivity varies to a great degree with the soil type and crops grown, and income from specialized crops fluctuates widely with market conditions.

If the preliminary investigations indicate that proper water control is feasible, that the soil is suited for the desired use, that the improved land can be used to immediate advantage, that the venture will have a high cost-benefit ratio, and that development can be properly financed, the prospective developer may want to get a detailed plan for reclamation.

The scope and cost of such plan will vary with the size and complexity of the project. On small areas the advisability of development may depend not so much on the land itself but on the experience of the farmer in handling organic soils and whether the crops suited for the soil will fit into his farming system.

On large projects the planning should be done by engineers experienced in drainage of peat and muck soils. The scope of the investigation might well include: Drainage and agricultural history; market facilities and income statistics; crop and vegetative requirements; longtime records of rainfall, evaporation, and temperature; geologic and ground water conditions; topographic surveys; soil surveys and physical land conditions; water control recommendations, including drainage and irrigation requirements with design rates and plan of control works; construction estimates and costs; maintenance recommendations and costs; total cost summary and cost-benefit ratio; financing methods; and annual cost assessments against benefits.

Once the venture of reclaiming a bog deposit has been decided upon, the first requirement is removal of excess water. The best time to start drainage normally is the driest season. First the inflow from adjacent lands should be blocked off and surface water removed to dry out the land enough for clearing and installing the drainage system. On ground subject to inundation (because there is not enough surface relief for proper drainage) or on ground subject to frequent overflow from nearby lakes or streams, protective dikes must be built around the area and pumps provided to remove the water.

In building the dikes it is best to use mineral soils—not peat—where practicable. Sometimes organic material may be added to sandy soils to reduce seepage through the dike. It may also increase fertility and aid in the growth of a vegetative cover to control erosion. Mucks high in mineral content and structurally stable often can be used to good advantage in dike work.

Frequently, however, peat will be the only material that can be used. In the Everglades, in fact, dikes of peat are often used to protect farms. The size of the dike depends on the difference in water levels inside and outside the shielded tract.

A dike built from the organic soils requires a larger embankment than one built from the heavier mineral soils. A well sodded, compacted dike of firm peat with a settled height of 5 to 6 feet, a bottom width of 15 to 20 feet and with side slopes of not less than 1:1 usually suffices to withstand water stages outside the dike up to a depth of 3 feet above land surface if the field water level inside is drawn down about 2 feet below the surface. If the dike is subject to wave action, a heavily matted sod on the dike and an offshore stand of willows or similar planting are desirable.

Dikes of fibrous peat will settle up to one-third of their original volume the first year. Sedimentary peats shrink much more. Allowances should also be made for slow shrinkage, after the first year, by oxidation. Sufficient soil should be left in the berm where it can be excavated and used periodically to build up the dike to keep it to grade.

Before the dike is constructed, it is desirable to remove the vegetation from beneath the base to assure a bond between materials. Also, to retard seepage and key in the bank, a trench about the width of a dragline bucket and 4 to 5 feet deep should be dug and backfilled with puddled organic soil. This puddle trench helps prevent leakage where the land has dried out and shrinkage cracks occur in the ground.

Shrinkage cracks may extend through the dike itself. A remedy is to shape, tamp, and sod a rough dike soon after the excess water has drained. If the soil is a sedimentary peat or a muck containing marl or any colloidal admixture that causes the material to slump, the soil may have to be excavated and allowed to drain before the dike can be shaped and completed. Sodding reduces maintenance by retarding subsidence and preventing wind erosion and rank growths of weeds.

Draglines or dredges are commonly used to construct dikes. The material should ordinarily be taken from outside the field, and an ample berm of undisturbed soil left between the dike and borrow channel. The water pressure outside the protected area then will be less apt to cause structural failure, the outside channel will serve to divert and allow the ponded water to escape faster, and the ditch will act as a firebreak.

The need for farm roads should be kept in mind when laying out the dike system, but using peat dikes for roadways lowers the dikes and makes them more subject to wind erosion. Dikes that are capped with rock or other suitable material are more stable and more usable as roads.

If a sluggish stream causes boggy conditions, surface drainage may sometimes be accomplished by straightening and increasing the size of the channel without diking. Before such a remedy is adopted, however, backwater flood stages, resulting from downstream obstructions, should be ascertained, and it should be remembered that the bog surface will subside with drainage.

In places where swampy conditions are caused or made worse by seepage of ground water, the problems of drainage are more complex, and the advice of a ground water geologist should be sought before costly reclamation work is undertaken. Seepage from surrounding uplands through the soil mantle may often be intercepted and diverted by cutoff trenches before it reaches the peat or muck area. If seepage is carried beneath the bog by a confining layer and then reaches the surface through a leaky roof, control measures are often expensive; although, where the rate of flow is moderate, relief wells have been used successfully. In many instances seepage, if it can be controlled, may be helpful during dry periods to supply water for irrigation.

ONCE THE LAND has been shielded from outside water, the next step is provision of field drainage. Soil that is very wet and spongy may require several seasons of progressive drainage before all the water-control facilities can be installed.

First, the main ditch leading from the pump, or other outfall, should be dug, the work proceeding upstream into the tract to be drained. Branching off from the main ditch, adequate laterals and open field drains should be constructed to dry out the land enough to proceed with the clearing and initial plowing.

The amount of labor required to bring the land under cultivation varies according to the native growth. Trees must first be cleared. Then it may be advantageous to put the area into pasture for several years to allow the stumps and roots to decay so they may be more easily removed.

If the ground is covered with grass, the first step is breaking. Light burning is permissible if it is done when the land is wet and the soil is not harmed. Initial breaking should be deep and done with a 24-inch plow if practicable. The land then is rolled with a heavy roller.

On raw, virgin peats, the land should be pastured. If drainage is good, the soil should be broken in with such crops as peas, oats, barley, or other coarse-seeded plants. It is suggested that the land be leveled as much as feasible in the early stages of development. It is ordinarily good practice to provide deep drainage for several years to improve the physical condition of the soil by aeration before the permanent water-control structures are installed.

The highest subsidence losses will occur immediately after the initial drainage and cultivation. The hydraulic design should be determined with respect to the anticipated surface elevation. The amount of initial subsidence to be expected will depend in large degree on the type of peat and past drainage history. Firm, fibrous peats may be expected to sink 12 to 24 inches during the first 5 years of tillage. The flaccid sedimentary peats often shrink up to three-fourths of their drained volume. An allowance of approximately 30 percent of the peat depth is suggested for newly drained sites and about 10 percent for previously drained agricultural areas. The annual subsidence rate after the first 5 years will depend on depth of drainage.

THE DESIGN of the drainage system must consider the selection of the proper runoff rate for the tract; the best layout of field drains to secure adequate soil drainage throughout the cropped area; and the problem of holding water levels at the correct depths for maximum crop yields, control of subsidence, and protection against frost.

Runoff requirements for organic soils depend on the frequency and intensity of the rainfall, the storage capacity of the soil, the value of the crops, and the sensitivity of the plants to immersion.

Plants are drowned when the root system is smothered and gaseous exchange is prevented. Oxygen normally is absorbed by the roots in exchange for carbon dioxide, which is cast out. Different plants vary greatly in their oxygen requirements, but the demand usually rises in response to such factors as sunlight and high temperature, which increase physiological activity. Thus crops tolerate flooding longer after a storm, when the weather is cool and cloudy, than when it is hot and sunny. Some plant roots can stand submersion better when there is a movement of the ground water, which can dissolve and remove the carbon dioxide and help supply the oxygen demand.

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H. A. Jongedyk and his associates, who investigated controlled drainage of truck and field crops grown on muck soils at Purdue University, concluded that a safe rate of storm removal would be a reduction in the ground-water level to a depth of 18 inches beneath the surface within 48 hours. They found that once the water level is that deep the urgency of additional drainage is reduced considerably.

In the selection of the drainage modulus—or runoff rate—the intensity and frequency of the rainfall are usually the most important elements.

It is not considered practicable to install farm drainage systems that will dispose of the maximum rainfall, and it appears to be good management to plan on losing a crop about once in 5, 10, or 15 years, the interval selected depending on the value of the crop that might be saved as balanced against the increased cost of providing additional drainage for very infrequent storms. In regions where intense rainfalls are frequent, the drainage system should be arranged so that at least part of the farm can be drained adequately during any storm by locating dikes and control gates with which runoff from other parts of the farm can be delayed when desired. Crops on at least part of the farm can be saved in that way.

The general opinion among growers in the Everglades is that facilities to remove 2 or 3 inches in 24 hours should be available on truck farms and 1 inch on cane and pasture lands. In the New York area, it is considered feasible to provide pumping capacity for 1 to 1.5 inches for high-value crops. In Indiana 0.37 to 0.5 inch a day seems satisfactory for meadow and pasture, 0.75 to 1 inch a day for field crops, and possibly as much as 2 inches for truck crops.

In districts where local requirements are not known, a handy guide for truck-crop drainage is to determine the frequency period for which protection against crop loss is economically justified and to plan on caring for the rainfall from a 2-day storm for the selected frequency period.

Technical Report 5 of the Miami Conservancy District, *Storm Rainfall in the Eastern United States*, revised in 1936, contains the results of frequency studies for excessive precipitation in the United States east of the 103d meridian. The maximum rainfall recorded up to 1932 during periods of 1 to 6 days in each quadrangle of 2° is given. Isopluvial charts also show the amount of rainfall that might be equaled or exceeded at any given locality in periods of 1 to 6 days, with a frequency of once in 15, 25, 50, and 100 years.

Miscellaneous Publication 204 of the Department of Agriculture, *Rainfall Intensity-frequency Data*, represents a series of 56 charts of the rainfall-intensity frequency relation for the entire United States for periods of 5 minutes to 1 day. Where the 2-day frequency is not available for the recurrence period desired, a close estimate can be obtained by adding 12 percent to the 1-day data in the bulletin.

The damage from excessive rains may be reduced somewhat by the high absorptive capacity of organic soils. The available soil water storage will vary with the depth of the water table, the moisture equivalent, and the time since the last rain. Under average conditions, where the water table averages about 2 feet deep before a storm, however, it may be estimated that 1 inch of rain will raise the water table about 6 inches, or that about 4 inches will be required to saturate the soil.

To illustrate the method of computing the drainage modulus: Assume a truck farm in the Everglades where the water table is held at a depth of 24 inches, there is no seepage inflow, and the crop justifies a protected frequency period of 10 years. From rainfall records at the Everglades Experiment Station, it is found that the 48-hour rainfall-expectancy rate for a 10-year interval for the 5-month period, November through March, which is the normal growing season for vegetables in this district, is 6.3 inches. Since the water level should be 18 inches below surface at the end of the 48-hour period, a 6-inch depth is available for ground storage which allows a credit for 1 inch of rainfall. Then $6.3-1.0=5.3$ inches in 48 hours, or a required drainage modulus of 2.6 inches a day.

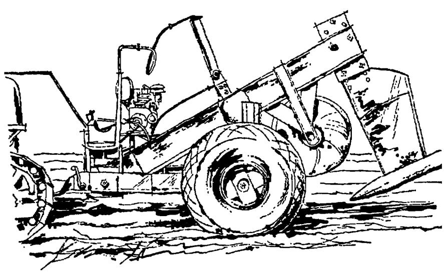
Again, assume a locality in the Great Lakes States, where local rainfall records are not available near latitude 43°, longitude 91°, and where the crop value justifies a crop-protection period of 15 years, with other factors remaining the same as before. From the isopluvial charts of the Miami Conservancy District, the maximum 2-day rainfall to be expected on the average of once in 15 years is 4.4 inches. The required 24-hour drainage modulus is $4.4-1.0=3.4$ inches in 48 hours, or 1.7 inches a day.

THE EXTENT to which field drainage is necessary depends on the proposed use of the land, the depth and internal drainage qualities of the organic soil, and the water-carrying ability of the subsoil. Reliance on open-ditch drainage alone or the incorporation of a tile system depends often on the acre-value of the crops that may be grown and the relative cost and convenience of the two types of drainage systems. In the firmer organic soils, mole drains can often be used to advantage in place of the more expensive tile systems. Their use in oozy peats or mucks is less successful.

In areas where there are no drainage patterns already established to furnish a clue, the layout of field drains is a perplexing problem. Proper spacing, as in the case of mineral soils, will depend largely on the effective permeability of the soil and the water-table requirements. Unlike mineral soils, however, soil moisture equivalents or laboratory classifications of permeability are of little aid in selecting proper drain spacing on peat and muck lands. On the other hand, field methods of determining effective permeability, such as the auger-hole method or the drain-function method, are of value in the hands of technicians.

Many of the organic soils can be cropped with only open-ditch drainage. No general rule can be given for their spacing, which varies from as close as 50 feet on some truck farms in the Great Meadows district of New Jersey to as far apart as 1,320 feet in the Florida Everglades. Widely spaced ditches can be used if the land has good internal drainage, especially if the soil is laminated by horizontal cleavage planes or the vertical drainage is good and the peat is underlain at shallow or moderate depth by permeable strata, which act as a horizontal aquifer to convey the soil drainage to the laterals and main drain. But muck soils with poor internal drainage, underlain by a silt, clay, or other impermeable subsoil, may require spacings too close to be practical. In fact, if the ground water movement is very sluggish, the practical drainage modulus allowable for the farm may be limited to the total flow that can seep into the field drains during the critical drainage period rather than be determined by the rainfall intensity.

Mole drains are a valuable supplement to open-ditch drainage where



they can be used. They aid greatly in equalizing water levels between ditches for both drainage and for subirrigation. Moling may be more effective in fibrous peats than in some of the sedimentary peats or soft plastic mucks. They are formed by drawing a bullet-nosed cylinder, 6 inches in diameter, through the soil to make a hole about 4.5 inches in diameter. The resulting mole drains should have a minimum depth of 30 inches below the surface to prevent closure of the holes by compaction during normal farming operations.

Mole drains are best established when the water table is below the proposed hole depth. Moles operating below the water table set up a partial vacuum, which tends to close the hole behind the bullet. The bullet draws a pressure of nearly 9 inches of mercury, the equivalent of about 11 feet of water, when operating 6 inches below the water table at normal tractor speed. The bullet should be vented to prevent this back pressure. Moling machines should not be pulled at high speeds; the slower the speed, the less tendency for the hole to close.

Mole drains are spaced 12 to 15 feet apart. Costs of moling in 1954 were 1 to 2 dollars an acre. Properly constructed moles in suitable soils should give effective service for 5 to 8 years. When they cease to function satisfactorily, new lines can be pulled in between the old drains.

WHERE THE ACRE-VALUE of the crop is high and soil conditions are suitable, tile underdrainage may be desirable. Such drains avoid cutting up the fields by ditches, save land area, eliminate open-ditch maintenance problems, and do away with weeds or sod along ditch banks.

The same general rules hold for installing tile systems in organic soils as in mineral soils, but several important differences must be borne in mind. Proper spacing, as for open drains, depends largely on the effective permeability of the soil and on requirements of the water table. Often the best intervals can be judged according to spacing used on nearby farms or observations of open ditches. Wide spacings may be tried first and additional lines added later if needed. Ordinarily lines are spaced 50 to 200 feet apart. The reed-sedge and woody peats usually drain well at spacings of 100 to 120 feet. If controlled drainage and subirrigation are used, close spacing of the drains is desirable to flatten out the undulations of the water surface between tile lines. If the surface soil has become dense and compacted and the vertical seepage is retarded or if extensive acreage is completely tiled, enough open ditches should be left to provide surface drainage during flash floods.

The gradient of the tile system will depend essentially on the slope of the land. When the field is to be subirrigated by reversing the flow in the system, the tile gradient should be held as low as drainage needs will permit. The minimum recommended gradient is 1 inch to 100 feet

Conventional flow formulas are used to determine sizes of tile, but standard tile smaller than 5 or 6 inches should be used with caution in bog soils, because small tile settle out of alinement easily and cause clogged lines. Long lengths of tile generally are preferred for peat and mucks, as they are more likely to stay in place. If it is necessary to lay tile in oozy soils the long, perforated type may be best.

The installation of tile should be delayed in fresh lands until several years of open-ditch drainage and cultivation have accounted for the heavy initial shrinkage losses. Then they should be installed as deep as feasible to allow for the slow subsidence of the surface caused by oxidation of the organic soil in the drained zone. A minimum depth of 4 feet is recommended; 6 feet is better where the subsoil and outlet conditions allow.

P. W. Manson and D. G. Miller, of the Minnesota Agricultural Experiment Station, found that the corrosive action on concrete varied with the acidity of a peat and the quality of the concrete. Rich mixes of high strength and low permeability gave the greatest resistance. All concrete drain tile installed in peat should be of at least the quality prescribed for extra-quality drain tile in standard specifications of the American Society for Testing Materials, designated C4–50T. Concrete in tile of this classification will have a compressive strength of 4,000 pounds to the square inch, or more, and an absorption of 8 percent or less. An organic soil with a pH value of 6.0

may be considered to be definitely acid. When that value drops much below 6.0, the use of concrete tile becomes a matter of doubtful economy. Clay tile that meet ASTM specifications are not subject to acid corrosion; both glazed and unglazed clay tile are satisfactory for use in organic soils regardless of the degree of acidity.

After the tile has been laid, special care must be exercised in blinding the tile line and in backfilling the trench to prevent puddling of the organic soil. When the soil is disturbed, water movement is greatly retarded.

B. S. Clayton, formerly of the Everglades Experiment Station, found that for vertical samples of Everglades peat the average depth of water passing through the top 18-inch layer which had been disturbed by tillage was 0.30 foot a day, that through the 18- to 36-inch layer was 27.3 feet, and that through a horizontal sample was 0.25 foot a day. The second vertical and horizontal samples were both from the undisturbed, brown, fibrous peat, and the wide difference of seepage rates through them is due to the structure of the partially decayed sawgrass residue, which provides small openings along vertical lines. The seepage rate through the top layer of soil was not much greater than that through the horizontal sample, because of structural changes by tillage. Thus, if the excavated peat, especially the dense plastic topsoil, is carelessly replaced around the tile, an impermeable ground water barrier that is formed will cut down seepage into the tile joints.

The joints of the tile should be covered with several inches of a porous material as gravel, cinders, or porous topsoil of mineral origin. Straw, sawdust, sod, or other organic materials may be used when they will be below the water table so that they are not subject to rotting. When the excavated peat cannot be replaced without causing a puddled condition, the trench should be backfilled with permeable material to within 12 or 18 inches of the surface before replacing the organic soils. If permeable material is scarce, vertical relief drains may be provided at intervals along the tile line to convey surface drainage downward to the depth of the blinding material.

Tile drains in organic soils sometimes do not work properly for several years. As the soil over the drains becomes aerated, plant roots penetrate the zone. As the plants grow and then die, the dead roots tend to leave open casts. Worms and organisms begin working in the live soil and improve the texture. Sometimes shrinkage cracks develop when the peat becomes dry and never completely close. During this time the permeability of the soil around the drain is improved by drainage to the extent that the tile serves effectively thereafter.

DRAINAGE IS ESSENTIAL for cultivation of peat and muck soils, but too much drainage will cause ruinous shrinkage and subsidence and make the soils undependable for crop production.

Each farm therefore needs a complete system of water control to provide drainage in wet weather and irrigation during dry weather. Control of ground water levels is desirable for attaining maximum crop production, for conservation of the soil, and for protection against frost.

Experience over the country and studies of drainage show that the best water tables for crop production in peat and muck soils vary with the rooting habits, maturity, and variety of the crop; the capillarity and water-holding characteristics of the soil; and the distribution of rainfall over the growing season.

The water-holding capacity of organic soils generally drops as the bulk density increases. For example, when they are near field capacity, Okeechobee muck, with a bulk density of 0.42, contains 30 percent water by volume; Okeechobee peaty muck, with a density of 0.29, contains 66 percent; and Everglades peat, with a density of 0.15, contains 75 percent. Ordinarily, the more compact and denser the soil, the higher the capillary column will rise above the water table but the slower the water will be transmitted upward.

The organic soils are exacting in their requirements for a satisfactory supply of moisture for crop production. The maximum levels that can be held without harmful effects are slightly below the zone of dense rooting.

P. M. Harmer, of Michigan State College, learned that most farm crops in Michigan produce best yields on muck with the water level held from 30 to 36 inches during the summer, although it may be held somewhat higher during early stages of growth. He stresses the importance of maintaining a fairly uniform water table during the greater part of the growing season to prevent the development of a deep-rooted zone during low-level periods that would be damaged by a rising level. Among the crops that preferred water levels under 30 inches were hay, cauliflower, celery, cucumbers, lettuce, parsley, peppers, radishes, spinach, squash, swiss chard, beets, tomatoes, turnips, strawberries, cranberries, and blueberries. Crops requiring water levels deeper than 36 inches were barley, oats, mangels, rye, and wheat.

A. R. Albert and O. R. Zeasman, of the University of Wisconsin, state that nearly all the special truck crops need a rooting zone of 24 inches or more of drained soil for good yield and high quality and that no material decrease in the yield of the crops occurs with drainage depths down to 36 inches. A depth of 48 inches is suggested for corn.

Research at the Minnesota Agricultural Experiment Station showed no marked difference between the average optimum depth of drainage for field crops and for truck crops, according to H. B. Roe. An average drainage depth of 36 to 40 inches is recommended for general farming. On bogs devoted to grass crops, a depth of 18 to 24 inches is suggested.

At Purdue University, onions, carrots, sweet corn, potatoes, and mint were grown on plots with controlled water depths of 15 to 38 inches. No important differences in crop growth occurred in plots having a 24-inch water table or deeper. Plots with a 15-inch water table yielded less, and the quality of the crops was poorer than those grown on the deeper water tables. A satisfactory minimum depth of 20 inches for the crops listed was suggested.

Studies at the Everglades Experiment Station indicated a water table of 18 to 24 inches was best for most truck crops. Celery and onions seemed to do best at the 18-inch level. Beans, cauliflower, and potatoes did best at 24 inches. Corn and lettuce required deeper levels up to 30 inches. Pasture grasses produced well on water levels of 18 inches but did not suffer up to 36 inches. The tolerance of sugarcane was found to vary with the variety.

We can assume from the investigations that a water table of 24 to 36 inches is desirable for most field and truck crops, but that mint, celery, canes, and pasture grasses will do best at shallower tables of about 18 inches. Grains and corn may need water levels up to 40 inches for best results. In dry regions the levels should be higher. In regions with well-distributed rainfall during the growing season they may need to be slightly lower.

Since a water table averaging 36 inches deep takes 1 to 2 inches more rain to saturate the soil than one averaging 24 inches, many farmers prefer to maintain low water tables for storage as a safety measure rather than provide additional runoff capacity. A water table held at the higher level of 24 inches, however, will cut oxidation losses over one held at the lower 36-inch level to the extent that the productive life of the soil will be increased an average of 50 to 80 percent. The exact rate of increase depends on climatic conditions and soil type. Thus in the long run it will prove cheaper to provide adequate runoff facilities in place of depending on storage capacity of the soil.

As a general rule, the higher the water level can be safely held without root damage, and the more consistently it can be maintained at the same depth after plant germination and initial root development, the better the crop yields will be. Further, the most practical way of holding the loss of peat and muck soils to a minimum is by controlled drainage whereby the water level is held as high as crop and field requirements will permit.

Proper water control presumes a water supply to be available to make up any deficit during dry periods. Water for such a system may come in part from the field ground water and seepage. Where this is insufficient to keep the water table to the desired level, water must be supplied from outside the field by gravity or by pumping into the system. In some places the needed water may be obtained from wells or from storage ponds.

Normal crop water consumption by evapotranspiration will amount to from one-eighth to one-fourth inch a day, the rate depending primarily upon solar energy on the leaf surfaces. That amounts to about 3,500 to 7,000 gallons of water used on each acre a day. That amount should therefore be available for irrigation in addition to seepage or other losses from the field.

As soon as drainage requirements are met, a system of control dams or gates should be provided to regulate water stages. The structures should have adjustable spillway openings that can be operated to raise or lower the water level in the drainage system in accord with needs of the day and should be capable of passing the designed runoff flow without undue restriction during floods.

Surface flooding is desirable for halting subsidence in organic soils and also for combatting certain diseases and weeds. The structure should therefore be capable of holding the water table near the surface when the land is not in use. The control dams should be spaced to hold differential water tables not exceeding about 1 foot, the number being determined by the slope of the field.

Dams to control ditch levels may be of timber, steel piling, masonry, or concrete. Metal culverts or other types with attached risers often are used in places where it is advantageous to have a road crossing combined with a control. The simplest control dams use the stop-log arrangement, which consists of grooved piers with wooden timbers spanning the space between them. The timbers are placed or removed individually, either with hooks, by hand, or by use of small, manually operated hoists. Small, portable, panel-type pumps that fit into the grooved openings are valuable for field irrigation where gravity flow is unavailable. Culvert pipes equipped with sliding headgates may be used, but trash accumulates worse behind any underflow type of spillway. On the larger developments, where high head-control structures are required, radial gates, roller gates, or sliding gates operated mechanically or manually are preferred.

Water checks in tile lines can be of simple construction. They consist of a wooden, steel, or concrete catch basin that has vertical grooves in the center section. When the boards are in place, impounded water backs up until it reaches the gate-board level and overflows into the tile below. Even simpler are galvanized iron plates, which can be slid into the joints between the tile and withdrawn as desired. The use of the catch basins, with control weirs, is to be preferred, as they need less attention and provide automatic relief in case of flash rainfall when the crest level is reached.

From a practical standpoint it is impossible to hold a precisely uniform level under the whole field, because the surface of the water table will form a series of undulations between the field drains whenever there is an appreciable movement of the soil water toward or away from the drains. Under drainage, the undulations will trough at the drains and crest about midway between them, while under subirrigation the positions will be reversed. The shape and gradient of the profile of the water table will vary with the effective permeability of the soil, being abrupt with low permeable soils and subdued with highly permeable soils. As the flow of ground water under gravitational influence diminishes, the slope of the water table becomes flatter.

In order to observe the actual ground-water levels in the field between the drains, it is suggested that shallow observation wells, properly cased, be sunk at strategic locations in the field. They are helpful in determining the water levels needed in the ditches to effect proper ground water levels under the crop.

Soil moisture usually is supplied through subirrigation by simply backing the water up in the ditches or tiles and allowing it to seep laterally through the soil. In soils where the water movement is very slow, however, this method may not be feasible, and overhead irrigation will be preferable. Also, if the water supply is limited or the land surface is too rough for subirrigation, overhead sprinklers are favored. They are used also during germination and for transplanting such crops as celery.

PUMPS ARE REQUIRED often for drainage of peat and muck lands and for irrigation during dry periods. Lifts are usually low in pumped districts on organic soils, and low-lift, high-volume pumps commonly are used. The design and construction of pumping stations for peat and muck lands follow the same principles governing pumping plants for other drainage. Allowance must be made for subsidence, however, and the intake must be low enough to provide for lowering the surface during the life of the installation.

Permanent installations are provided with permanent foundations and protected from the weather by housing. Costs of the farm pumping plants range generally from 150 to 300 dollars per cubic foot per second for the complete installation.

Crops on organic soils are damaged by cold oftener than are similar crops grown on nearby mineral soils. Organic soils occur in depressions, where the heavy, cooler air settles. The thermal characteristics of organic soils differ markedly from those of mineral soils. Organic soils, in comparison with mineral soils, have a high coefficient of absorption and emission of radiant energy; a high heat capacity, which increases with moisture content; and a low coefficient of heat conductivity, which can be increased by compaction or added moisture.

During daylight, the dark organic soils absorb more radiant energy than the light-colored mineral soils. Its high heat capacity demands more heat to raise soil temperatures than do the mineral soils, but this same capacity is conducive to more storage of energy at equal temperatures than mineral soils. This stored heat is released on clear nights into outer space as radiant energy, which is not effective in warming the air because of the poor heat-absorptive quality of clear air.

Under the laws of heat exchange, the surface soil must receive and absorb as much energy as it is radiating. Since the heat conductivity of the dry organic soil is low, the heat is robbed from the air next to the surface, and the temperature drops. If there is no wind movement to mix the air, the temperature near the ground surface drops quickly. An upward temperature gradient, or temperature inversion, thus is established.

If clouds intervene to absorb and reflect the nocturnal radiation or if a breeze mixes the air to prevent the layer of air near the ground from excessive cooling, frost damage is less apt to occur.

Heat transmission is more rapid in moist soils than in dry. A dry surface layer on peat or muck is a poor conductor, and it retards the transfer of heat from the subsoil to the surface to replace radiant losses. On the other hand, a rolled, compacted, moist soil augments the exchange and consequently reduces the chances of crop damage on the cool, clear, calm nights.

Surface flooding of the area or even raising the water level in the field is an effective method of protecting it against frost. The practice is safest in places where the water-control system can be operated to obtain rapid change in ground-water levels. When it is doubtful whether the crops can tolerate the necessary higher water levels, sprinkler irrigation is safer and as satisfactory.

The presence of a body of water, such as a lake, cushions sudden changes in temperature and reduces the risk of frost damage. Muck areas close to the Great Lakes are especially favored. The lands near Lake Okeechobee in Florida are similarly protected against cold spells and are highly prized for growing truck crops.

Air drainage and wind movement are important considerations in frost prevention, and the value of windbreaks to prevent soil blowing and crop damage should be balanced against their hindrance to air movement and mixing in places where tender crops are grown. Helicopters and wind machines have been used with varying degrees of success to stir the air over fields.

Organic soils that have been tilled long enough to develop a mucky surface condition are better heat conductors than raw peats and therefore are less frosty and safer for tender crops than the newly developed lands. A surface covering of sand, such as is used in cranberry bogs, also reduces danger of frost damage.

Frosts on muck can be combatted by the selection of crops that are least susceptible to damage. H. C. Thompson, of Cornell University, grouped vegetables into three classes with respect to cold resistance: Hardy (which will stand hard frosts), such as kale, spinach, turnip, mustard, onion, peas, and cabbage; half-hardy (those that will withstand light frost) such as beets, carrots, parsnips, celery, and chard; tender (those that will not withstand any frost), including beans, sweet corn, lima beans, squash, pumpkins, melons, cucumbers, okra, tomato plants, eggplant, and pepper plants.

THE MANAGEMENT of organic soils differs from the management of mineral soils in several respects. Peat is porous and open and ordinarily does not require plowing every year. In fact, rolling and packing is often important in the management of such land. Compaction allows the roots to come in closer contact with the soil. It facilitates the rise of water from below, which benefits germination, lowers frost hazards, and tends to reduce soil blowing during dry weather. Generally, cultivation should be more shallow than for mineral soils, especially after root development begins.

Commercial fertilizers ordinarily are more desirable than manure. Nitrogen may be needed on raw peats, on the more acid peats, or on poorly drained areas, but less often on good, thoroughly decomposed organic soils, which especially require potassium and phosphorus and generally need such microelements as copper, manganese, zinc, and boron. Common salt benefits some crops. The amount, kind, rate, and time of fertilization depend on the crop to be grown, the climate, the chemical and physical nature of the peat or muck, and its drainage, previous fertilization, and length of time under cultivation.

On the basis of soil tests and degree of drainage, special recommendations have been prepared by many of the State agricultural experiment stations on fertilizer grades, placement, rates of application, and the addition of microelements.

With proper control and management of water, many crops can be grown on organic soils. In Florida, vegetable crops, including beans, sweet corn, pepper, cabbage, and celery, are grown for the winter market. Sugarcane and pasture grasses, especially St. Augustine grass, do very well. Ramie, a fiber, thrives on these soils. In California, corn, potatoes, onions, sugar beets, asparagus, celery, and other special vegetable and field crops are grown on the organic soils. In Pacific Northwest, peat and muck lands produce forage and the vegetable crops that are suited to climatic conditions and market demand. Cranberries are grown in Massachusetts, Wisconsin, New Jersey, Washington, and Oregon. The plant grows wild only on acid peat or muck bogs—a good indication of the soil requirements of the plant. Blueberries do well under similar conditions.

In the organic soils of Sanpete County, Utah, the only practical known method of securing a moisture supply is by flooding the soil during late winter and early spring. The Utah Agricultural Experiment Station recommends a crop rotation on peat of barley or oats, 1 year; sweetclover, 1 year; or barley or oats, alternating with a clean, firm, summer fallow. On mucks a longer rotation of crops, including canning peas and potatoes, is suggested. The commercial production of celery and cabbage on the mucks there appears to depend on development of an adequate water supply for supplemental irrigation.

In the Great Lakes States, peat and muck soils are used in several systems of crop production, depending on size and quality of the deposit, location in relation to markets and climate, drainage facilities, and the experience and preference of the operators.

The University of Wisconsin Extension Service lists these uses for the organic soils: Supplementary forage production on farms where major cropping is on upland areas; both forage and cash crops on farms where no upland is available (on these farms sweet corn, cabbage, grass seeds, onions, mint, root crops, and some leafy vegetables are raised if frosts are not too much of a hazard, a ready market exists, and labor and equipment is available); special crop production if crops of high gross income, which require good drainage and intensive cultural and land management practices, can be grown. Income from such crops is subject to considerable fluctuation, and diversification of crops is indicated for the average farmer.

In New York and New Jersey, good agricultural organic soils are desirable for the production of truck and other special crops, because they are close to city markets. The more acid peats are used for cranberries or mined for use in lawn improvement and other horticultural purposes. In Maine the present use of the peats is for litter or pulp production.

THE RECLAMATION of the Everglades of Florida illustrates water-control methods that have been employed in the reclamation of large bodies of organic soils.

The Florida Everglades contains more than 3,100 square miles of peat and muck soils. The soils were formed in a sedimentary trough of limestone about 100 miles long and 40 miles wide, southward from Lake Okeechobee to the sea. Arms of the Everglades also extend partly around the eastern and western shores of the lake. The Everglades is bordered on the east by the narrow Atlantic coastal ridge, which reaches an elevation of about 15 feet, and on the west by a low, anticlinal arch, which rises to an elevation of about 25 feet and embraces the areas known as the Big Cypress Swamp and the Devil's Garden.

In past geologic times, Lake Okeechobee, an almost circular fresh water lake of about 725 square miles, received the water carried by the Kissimmee River and other tributary streams, which drain a watershed of about 4,000 square miles. The lake, having no definite outlet, overflowed its south and eastern rim when it reached a stage about 20 feet above sea level. The overflow, together with an annual rainfall of more than 60 inches, moved slowly through the thick vegetation over the almost level plain of peat and muck to escape eastward through a few small rivers transecting the east coast barrier ridge or to pass eventually to the sea through dense mangrove forests at the tip of the peninsula.

Silt, clays, and organic colloids were carried in suspension and deposited during intermittent overflows near the shore of the lake to intermix with the remnants of plants to form mucks. Because those soils contained sufficient amounts of the microelements that the peats lacked and were relatively free from frost, they became highly prized cropland when they were drained. In the ancient floodways along the eastern and western margins of the swamp, submersed succulent aquatics grew and later formed a very light sedimentary peat, which was found to be unsuited for reclamation and is used for water storage and as a fish and wildlife refuge. Most of the Everglades soils, however, were derived from sawgrass and related marsh plants, which formed a light, felty, brown, fibrous, low-moor peat with a low ash content. When drained, fertilized, and augmented by minor elements, it breaks down into an excellent field soil under tillage. This type of soil today makes up the greater part of the productive agricultural lands of the 'Glades.

The total area of the Everglades mantled by peats and mucks is approximately 2 million acres. Because of shallow depths or poor soil type, something less than half of that acreage is deemed suited for agricultural development.

The original condition of the Everglades has been greatly altered by drainage works, first by State and local interests and later by the Federal Government. Premature attempts at drainage began about 1880. Intensive drainage operations began in 1906 after the Everglades Drainage District, including approximately 4.5 million acres, was created by the State legislature. The early plan was to extend the several short, coastal rivers through the marsh to tap Lake Okeechobee, but that soon was found to be inadequate to control high lake stages. The lake was impounded by muck dikes to block escape of lake water into the Everglades, and additional outlets were constructed directly to the sea. The original canal system was left to serve the peat and muck lands. Even then the system proved inadequate; lands were overdrained during the dry season and underdrained during the rainy season. In 1926 and 1928 the muck dikes around Lake Okeechobee were swept away by hurricane-driven lake water. The resultant overflow and flood caused great property damage and loss of life. Control of the lake stages to provide for flood protection and navigation was undertaken by the Federal Government. The muck dikes were replaced by substantial rock levees. Enlarged outlet canals, provided with hurricane-proof control gates, were constructed. Those measures have proved to be effective against overflow.

Meanwhile it was found that farming in the Everglades could be successful only if the fields were surrounded by dikes to prevent overflow by high water from the canals or surrounding lands. Reversible pumps were also found necessary to pump water from the fields into canals in wet seasons and water from the canals into the fields during the dry season. For local water control, subdrainage districts were organized. The districts have constructed ditches, dikes, and pumping plants, which afford varying degrees of protection for about 150,000 acres. Individual landowners outside subdrainage districts have provided water-control facilities on some 40,000 acres.

Investigations by the Department of Agriculture and other agencies published in 1948 revealed that improper water control had resulted in overdrainage during dry periods, with excessive loss of soil from burning and oxidation. The average loss of depth was found to average about 1.25 inches each year. The better soils in the northern Everglades lost 40 percent of their original volume during 40 years of drainage. Salt water from the ocean also found its way inland under the coastal cities during periods of low rainfall.

Heavy rainfall and hurricane winds in 1947 caused inundation of the entire Everglades area, even though overflow from Lake Okeechobee was blocked. The flood damaged nearly 50 million dollars worth of property and revealed that works of the Everglades Drainage District were insufficient for flood control.

In 1949 a comprehensive plan of flood control and water conservation for central and southern Florida, including the Everglades, was drafted and authorized by the Congress and the Florida Legislature as a cooperative Federal, State, and local program. Plans called for substantial rock levees as an additional protection against overflow, enlarged arterial canals designed to transport water to giant pumping stations capable of removing 0.75 inch of runoff in 24 hours, and pumping of wet-weather runoff from agricultural lands into Lake Okeechobee and into leveed areas of the Everglades set aside for water conservation, where it will be stored for irrigation use in dry weather.

Pumping installations in the Everglades range in size from small portable field pumps, capable of moving 500 gallons a minute, to giant plants for use in the operation of the Central and Southern Florida flood-control program. One such plant on the West Palm Beach Canal serves an agricultural area of 230 square miles. It has a designed capacity of 4,800 cubic feet a second at a lift of 11 feet, with a pump efficiency of 75 percent. The plant contains 6 individual pumps of 800 cubic feet capacity and powered by diesels of 1,600 horsepower. The total construction cost of the plant is estimated at around 3.5 million dollars.

Most of the subdrainage district pumping units use screw-type pumps of capacities of 30,000 to 60,000 gallons per minute and are powered by diesel engines. The units are so arranged that water may be pumped into the drainage system when needed. Records kept on four large pumping districts from 1933 to 1938 showed the average static lifts varied from 3.5 to 4.4 feet. The mean depth of water pumped off the districts varied from 2.3 feet to 4.4 feet annually. The total annual cost of pumping, including fixed charges, which amounted to about two-thirds of the total cost, varied from 1.45 dollars to 2.57 dollars an acre.

In the Everglades, where the majority of individual farm pumps have capacities of 5,000 to 30,000 gallons per minute, requirements for pumping installations are typical of those for most peat and muck lands. In meeting those requirements, two types of pumps are most commonly used. In places where portability and reversal of flow are desirable features, a panel-mounted, modified centrifugal pump has found favor. It has a vertical shaft and double intake openings with peripheral flow produced by an impeller within a volute casing. A flap valve prevents backflow. Operation tests showed the pool-to-pool efficiency of this pump varied from 30 to 40 percent at lifts of 3 to 9 feet and at different speeds, with little variation in efficiency because of changes in speed or lift.

For permanent installation, a popular type is the axial flow, 3-bladed, propeller pump. It is usually mounted within a double-decked chamber, with intake from the lower chamber. A floating bell, activated by the upward flow, settles to seal off backflow when pumping ceases. Direction of flow is controlled by the manipulation of stoplogs within the grooves of the upper and lower chambers. A similar pump, with the same impeller and general design characteristics, is enclosed in a tubular casing for portability. It is popular for semipermanent installation where pumping over a levee is desirable. The chamber-mounted type varies in efficiency from 45 to 60 percent.

Internal combustion engines are in universal use in places where pumps are used primarily for drainage. Electric motors for pumping in the Everglades are limited to use for irrigation, where power failure during storms is not detrimental. In other districts not visited by hurricanes the use of electric power may be desirable because of the facility with which water stages can be controlled.

The use of open ditches, supplemented by mole drains, is accepted practice in the Everglades. Here, the ditch systems have laterals a half-mile apart on section and half-section land lines. The farm ditches are dug at right angles to the laterals and are commonly spaced 660 or 1,320 feet apart. Thus the farm is divided into fields of 40 or 80 acres and drainage units of 20 to 40 acres. The closer spacing is needed for truck crops and the wider spacing for sugarcane and pasture. Mole drains 12 to 15 feet apart are pulled into the farm ditches at right angles to them.

The laterals are about 15 feet wide and 4 to 6 feet deep. The farm ditches have nearly the same depth but are narrower. The fibrous peat has a predominantly columnar cleavage and the ditchbanks will stand on steep slopes. Some ditches are dug with almost vertical sides, and side slopes are seldom flatter than 0.5 to 1.

As the land is practically level, a fall of 3 inches to the mile is usually used in computing ditch sizes. A coefficient of roughness "n" of 0.035 for the laterals and 0.040 for the smaller farm ditches is used with the Manning formula. Those fairly high values are necessary because of the rapid growth of subtropical aquatic plants, such as water hyacinths, paragrass, and submersed mosses, which reduce the flow capacity.

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The Disposal of Seepage and Waste Water

William W. Donnan and George B. Bradshaw

An estimated 8 million acres of land in the West need drainage. An additional 8 million acres would benefit from better drainage.

A serious economic problem hangs thereby. Most irrigated areas are put into production only after large sums are spent for developing a water supply, conveying it to farms, and leveling land. If more money must go into drainage and reclamation, where is the profit?

It seems a paradox that drainage problems should occur on lands that we consider arid. What causes them?

Perhaps the foremost cause is excessive use of water. Water that is plentiful and cheap often is used in excess. The result is a general waterlogged condition. Wild flooding, continuous irrigation, lack of waste outlets, and excessively long irrigation runs tend to promote waterlogging.

A second cause is seepage from canals, laterals, and ditches. Of the 135,000 miles or more of irrigation canals and laterals in the 17 Western States, only 6 to 8 percent are lined. The rest are untreated earth channels. They are the cheapest to build, but they permit seepage losses that may amount to 70 percent of the water diverted into them. The seepage enters underground strata at elevations higher than those of the irrigated lands and often—as in South Platte Valley in Colorado, the North Platte Valley in Nebraska, and the Big Horn Basin in Wyoming—becomes a direct source of waterlogging of lower lying areas.

A third cause is the inherent stratification of irrigated soils in the West. Many irrigation developments were feasible because they included a plan for irrigating the broad, flat, alluvial